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Economic Benefits Resulting From Irrigation Water Use: Theory and an Application to Groundwater Use

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Abstract. Traditional economic analysis using a crop production function approach has assumed that all variable factors, including irrigation water, are fully employed in the crop production process. However, this paper first demonstrates that economic benefits of irrigation water are overestimated when the crop production function, and therefore the irrigation water demand function, is expressed in terms of irrigation water supplied, rather than consumptive irrigation water use. Second, the paper demonstrates that the magnitude of the estimation bias is proportional to the rate of irrigation water losses through leaching, runoff and evaporation. Consequently, the model misspecification problem would lead to increased irrigation water use and reduce incentives for farmers to adopt improved irrigation technologies.

Key words: applied water, consumptive water use, economic benefits, indirect-profit maximization, misspecification bias

JEL classification: Q25, Q2

1. Introduction

An important class of resource economic problems exist where the rate of consumptive use of an input is less than the amount of this input applied. Problems of this type are common with agricultural production practices that use irrigation water and agricultural chemicals. Not all nitrogen fertilizer applied to a crop is consumed by a crop's plant. A portion of nitrogen fertilizer applied may leach into groundwater or is lost through runoff, volatilization and denitrification. Similarly, a portion of irrigation water applied to crops is also consumed, while another portion may percolate through the crop root zone and on to an aquifer, or is lost through runoff and evaporation. Economists, when conducting economic analysis, have overlooked the difference between the rate of input application and the rate of consumptive use in the specification of irrigation water demand functions (Feinerman 1988; Feinerman and Knapp 1983; Gisser 1983; Gisser and Sanchez 1980; Kim et al. 1989; Knapp 1983; Nieswiadomy 1985) or in the specification of nitrogen fertilizer demand functions (Fleming et al. 1995; Kim et al. 1993; Kim et al. 1996).

The indirect-profit maximization approach has been widely used for the estimation of economic benefits resulting from the use of an agricultural production factor to avoid complexities associated with the estimation of a multiproduct-multifactor production function. For resource issues involving irrigated agriculture, traditional economic analyses using a crop production function approach have assumed that all variable factors, including irrigation water, are fully employed in the crop production process. Most economists have used an irrigation water demand function derived from a crop-water production function that was specified based on the amount of irrigation water applied. A few exceptions to this approach include the works by Caswell and Zilberman (1986), and Wu et al. (1994) who specified representative farm-level crop-water production functions based on consumptive irrigation water use.

Recently, Kim et al. (1997b) demonstrated that within the context of a Cobb-Douglas crop production function, if the application rates of inputs such as nitrogen fertilizer or groundwater for irrigation are used in the estimation of the crop production function rather than their consumptive use, the productivity of the input is overstated. Furthermore, Kim et al. (1997a) demonstrated that within the context of an optimal control model of nitrogen fertilizer use, the use of an estimated nitrogen fertilizer demand function based on the nitrogen fertilizer application rate would result not only in overestimation of economic benefits, but also in supra-optimum levels of nitrogen fertilizer application and groundwater nitrate stocks at the steady state. However, both studies have not vigorously analyzed how the misspecification bias associated with using a factor demand function, for either nitrogen fertilizer or groundwater for irrigation, estimated based on the quantity of the factor applied rather than its consumptive use, result in the overestimation of economic benefits of factor use under the indirect profit-maximization model.

The objective of this paper is to demonstrate that economic benefits estimated using an irrigation water demand function based on application rates are overstated, and that the magnitude of the overestimation bias is proportional to the rate of irrigation inefficiency. The source of the model misspecification problem under the indirect profit-maximization model, and its effects on the estimation of economic benefits resulting from irrigation water use are investigated under alternative factor-demand specifications.[1] A numerical example includes the estimation of net economic benefits resulting from irrigation water use for corn production in the Nebraska Mid-State area. Even though our discussion is confined to the misspecification bias associated with a model of irrigation water use, the discussion here can also easily be applied to problems involving nitrogen fertilizer use where the nitrogen application rate differs from the crop's consumptive use of nitrogen (Kim et al. 1997a).

2. The Model Misspecification

Because of farm inefficiencies in both irrigation systems and water management, crop plants make use of an amount of water which is less than total irrigation water applied. The crop plant's production process then fully employs only the consumptive-use portion of applied water, meaning that the crop-water production process is dependent on the consumptive-use portion of irrigation water. It will be shown, in the context of an indirect profit-maximization model, that economic benefits resulting from irrigation water use are over-estimated when the irrigation water-demand function is based on a crop-water production function that is specified using irrigation water applied.

Based on the literature, the normalized-quadratic profit function has been frequently used to characterize the economic benefits of agricultural production technology (Huffman and Evanson 1989; Shumway 1983). The factor demand functions derived from the normalized-quadratic profit function are linear in normalized prices. The use of a linear irrigation water demand function is easily tractable mathematically. The Cobb-Douglas production function is also widely used for the derivation of factor demand functions which are nonlinear. Therefore, the overestimation bias associated with estimating economic benefits is evaluated for two cases, both linear and non-linear irrigation water demand.

2.1. Case of a Linear Irrigation Water Demand

Let W and W^* be the amount of irrigation water applied and the consumptive use of irrigation water, respectively, such that:

$$W^* = \gamma W, \quad 0 < \gamma < 1, \tag{1}$$

where γ is a coefficient of irrigation efficiency.[2] Furthermore, let the crop-water production function be quadratic in consumptive irrigation water as follows:

$$\begin{aligned} Y(W^*) &= aW^* - (b/2)(W^*)^2, \quad a, b > 0,\ \delta Y/\delta W^* > 0 \\ &\text{and } \delta^2 Y/\delta (W^*)^2 < 0, \end{aligned} \tag{2}$$

where Y is output. The crop production function in equation (2) assumes that all of the consumptive irrigation water, W^*, is fully employed in the production process. The remainder of irrigiation water applied, $W - W^* = (1 - \gamma)W$, is lost through leaching (percolation below the crop root zone), runoff, and evaporation.

The consumptive irrigation water demand function obtained from equation (2) is then represented by:

$$\begin{aligned} &= P_y[\delta Y(W^*)/\delta W^*] \\ P_w^* &= P_y[a - bW^*], \end{aligned} \tag{3}$$

where P_y is output price. It should be noted that the marginal economic benefits associated with the consumptive irrigation water use, W^*, are valued in terms of P_{w^*}, that is, the marginal benefits of consumptive irrigation water use.

Since irrigation water costs are often measured on the basis of irrigation water applied, it is desirable for comparative reasons that marginal economic benefits resulting from irrigation water use be valued in terms of P_w, that is, the marginal benefits of applied irrigation water. Therefore, the consumptive irrigation water demand function valued in terms of P_w is derived from the crop production function (2) as follows:

$$\begin{aligned} P_w &= P_y[\delta Y(W^*)/\delta W^*][\delta W^*/\delta W] \\ &= \gamma P_y[a - bW^*]. \end{aligned} \tag{4}$$

By comparing equations (3) and (4), P_w from equation (4) can be represented in terms of P_{w^*} from equation (3) as follows:

$$P_w = \gamma P_{w^*}. \tag{5}$$

Equation (5) reveals that when irrigation inefficiency exists, the relationship between the marginal benefit of the consumptive-use water quantity, W^*, valued on the basis of its consumptive-use contribution, and when it is valued on the basis of its application requirement is proportional. More specifically, equation (5) demonstrates that irrigation inefficiency effectively devalues the marginal economic benefits of W^* by $(1 - \gamma)P_{w^*}$, when valued on the basis of its application requirement. The rate of irrigation efficiency, γ, serves as an exchange rate between the marginal benefits of W^* valued on the basis of its contribution to crop productivity (its consumptive use), and when valued on the basis of its application requirement.

For a graphical illustration, the consumptive irrigation water demand functions presented in equations (3) and (4) are represented in Figure 1. These equations are mathematically equivalent, with each irrigation water demand function representing the image of the other under a linear transformation defined by equation (5). For instance, inserting equation (5) into equation (4) results in equation (3). Figure 1 demonstrates, then, that the difference in the value of the marginal benefits of W^* when valued in terms of P_{w^*} (curve AC), and when valued in terms of P_w (curve BC), is $(1 - \gamma)P_{w^*}$.

Total economic benefits estimated using the consumptive irrigation water demand function in equation (3) are represented by:

$$B(W^* : P_{w^*}) = \int_0^{W^*} P_y[a - bx]\delta x = P_y[aW^* - \frac{b}{2}(W^*)^2], \tag{6}$$

which are valued in terms of P_{w^*} and represented by the area OAC in Figure 1. Similarly, total economic benefits estimated using the consumptive irrigation water demand function in equation (4) are represented by:

$$\begin{aligned} B(W^* : P_w) &= \int_0^{W^*} \gamma P_y[a - bx]\delta x \\ &= \gamma P_y[aW^* - (b/2)(W^*)^2] \\ &= \gamma B(W^* : P_{w^*}) \text{ from equation (6),} \end{aligned} \tag{7}$$

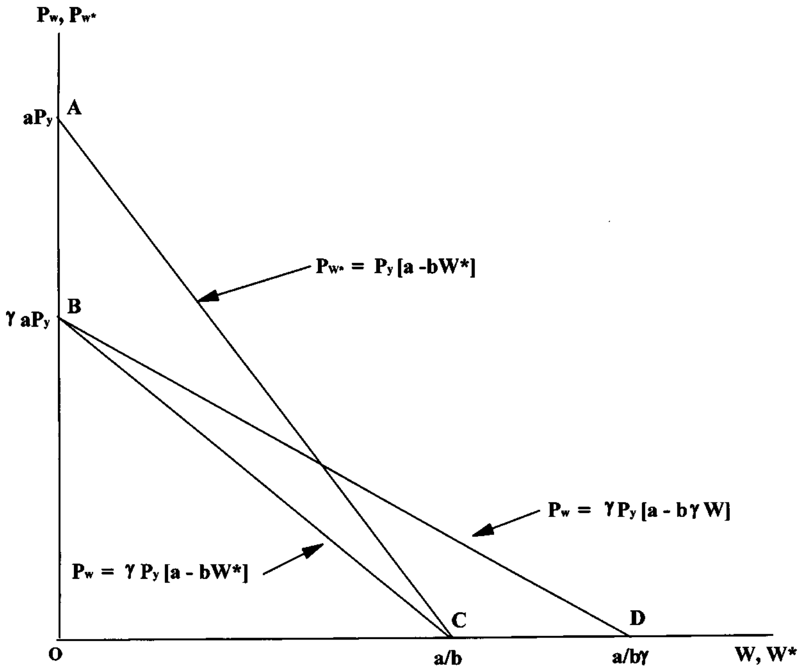

Figure 1. Irrigation water demand curves based on applied water (*W*), consumptive irrigation water (W^*), and their respective prices P_w and P_{w^*}.

which are valued in terms of P_w and represented by the area OBC in Figure 1.

To evaluate whether economic benefits estimated using an irrigation water demand function based on applied water correctly measure economic benefits of irrigation water use, first requires deriving an applied water demand function valued in terms of P_w, and secondly, comparing these results with the consumptive-use demand function valued in terms of P_w.

The quadratic crop production function based on irrigation water applied is obtained by inserting equation (1) into equation (2) as follows:

$$Y(W) = a\gamma W - (b\gamma^2/2)W^2. \tag{8}$$

The irrigation water demand function based on an application rate, and valued in terms of P_w, is then derived from equation (8) as follows:

$$\begin{aligned} P_w &= P_y[a\gamma - b\gamma^2 W] \\ &= \gamma P_y[a - b\gamma W], \end{aligned} \tag{9}$$

which is also represented in Figure 1 (curve BD).

The irrigation water demand function presented in equation (9) is also mathematically equivalent to the consumptive irrigation water demand functions presented in equations (3) and (4). Inserting equation (1) into equation (9) results in the consumptive irrigation water demand function valued in terms of P_w as presented in equation (4). Similarly, inserting equations (1) and (5) into equation (9) results in the consumptive irrigation water demand function valued in terms of P_{w^*} as presented in equation (3).

Total economic benefits estimated using the irrigation water demand function presented in equation (9) are represented by:

$$\begin{aligned} B(W : P_w) &= \int_0^W \gamma P_y[a - b\gamma x]\delta x \\ &= \gamma P_y[aW - (b\gamma/2)W^2], \end{aligned} \tag{10}$$

which is represented by the area OBD in Figure 1.

Inserting equation (1) into equation (10) results in the following:

$$\tilde{B}(W^* : P_w) = P_y[aW^* - \frac{b}{2}(W^*)^2]. \tag{11}$$

The right-hand side of equation (11) is identical with the result in equation (6). For this reason, Gisser and Johnson (1983) claimed that the economic benefits estimated using the consumptive irrigation water demand function as presented in equation (6), and those estimated using an irrigation water demand function based on an application rate as presented in equation (10) are commensurate, and therefore, economic benefits can be correctly estimated using the irrigation water demand function based on applied water.

However, contrary to the Gisser and Johnson claim, economic benefits presented in equations (6) and (11) are not commensurate. Economic benefits presented in equations (10) or (11) are valued in terms of P_w, while those presented in equation (6) are valued in terms of P_{w^*}. To evaluate whether economic benefits estimated from the irrigation water demand function based on applied water correctly represent economic benefits associated with irrigation water use then, the economic benefits presented in equation (11) must be compared with those presented in equation (7). Upon comparing economic benefits presented in equations (7) and (11), it is clear that economic benefits estimated using the irrigation water demand function based on applied water would be overestimated by a portion attributable to the irrigation water lost through runoff, evaporation and leaching (or the rate of irrigation inefficiency, $(1 - \gamma)$). That is,

$$B(W^* : P_w = \gamma \tilde{B}(W^* : P_w) = \gamma B(W : P_w). \tag{12}$$

For a given unit cost of irrigation water, *r*, the total net economic benefits (NB) resulting from the use of irrigation water for farmers are then represented (in Figure 2) as follows:

$$\begin{aligned} \text{NB} &= \text{the area OAeW}^* - \text{the area OrfW} \\ &= \text{the area rAe} - \text{the area W}^*\text{efW}, \end{aligned} \tag{13}$$

while the area eAf represents the social loss of economic benefits (social economic cost) attributable to the irrigation water lost through runoff, evaporation, and

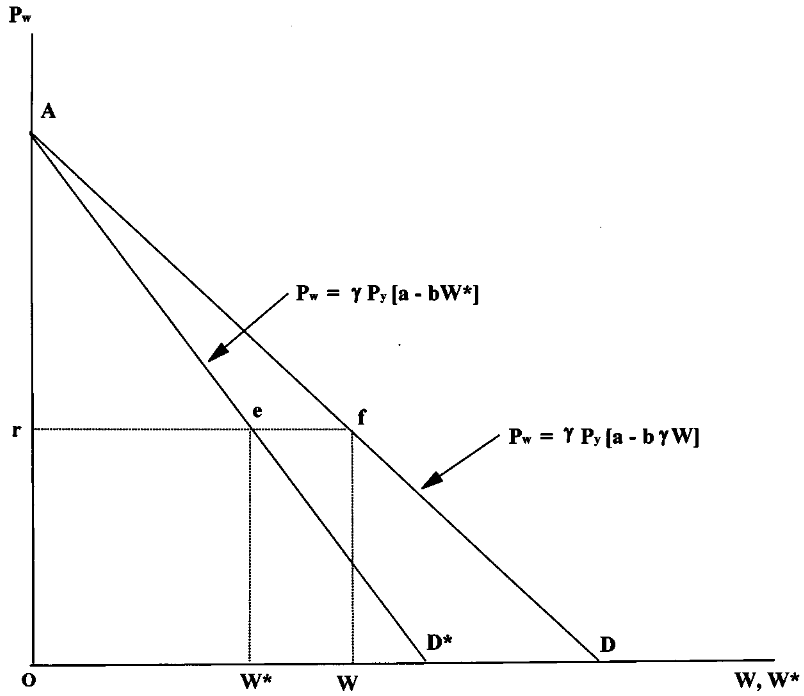

Figure 2. Linear irrigation water demand curves based on applied water (W) and consumptive irrigation water (W^*) use.

leaching, or the rate of irrigation inefficiency. The area W*efW represents the additional farmer cost associated with the rate of irrigation inefficiency. As improved irrigation technologies are adopted, the irrigation efficiency coefficient increases, and therefore, the irrigation water demand curve AD rotates to the left toward AD* so that total net economic benefits for farmers increase by reducing the area W*efW. At the same time, the social economic costs of irrigation inefficiency also decline because the area eAf declines.

2.2. CASE OF A NONLINEAR WATER DEMAND

Let the crop-water production function based on consumptive irrigation water use be represented by:

$$Y(W^*) = \alpha(W^*)^\beta, \tag{14}$$

where ($\alpha > 0$) and ($0 < \beta < 1$) to reflect a decreasing return to scale. Then inserting equation (1) into equation (14), the crop-water production function based on the irrigation water application rate is represented as follows:

$$Y(W) = \alpha\gamma^\beta W^\beta. \tag{15}$$

The consumptive irrigation water demand function valued in terms of P_w is obtained from equations (1) and (14), and represented by:

$$\begin{aligned} P_w &= P_y[\delta Y(W^*)/\delta W^*][\delta W^*/\delta W] \\ &= \gamma P_y \alpha\beta (W^*)^{\beta-1}, \end{aligned} \tag{16}$$

while the irrigation water demand function based on applied water is derived from equation (15) and is represented by:

$$P_w = \gamma^\beta P_y \alpha\beta (W)^{\beta-1}. \tag{17}$$

Total economic benefits, $B(W^*: P_w)$, estimated with the consumptive irrigation water demand function in equation (16), are represented by:

$$\begin{aligned} B(W^* : P_w) &= \gamma P_y \alpha\beta \int_0^{W^*} Z^{\beta-1} \delta Z \\ &= \gamma P_y \alpha (W^*)^\beta, \end{aligned} \tag{18}$$

while total economic benefits, $B(W: P_w)$, estimated from equation (17) are represented by:

$$\begin{aligned} B(W : P_w) &= \gamma^\beta P_y \alpha\beta \int_0^{W} X^{\beta-1} \delta X \\ &= \gamma^\beta P_y \alpha W^\beta. \end{aligned} \tag{19}$$

To compare economic benefits presented in equations (18) and (19), insert equation (1) into equation (19), which results in the following:

$$\tilde{B}(W^* : P_w) = P_y \alpha (W^*)^\beta. \tag{20}$$

Then, comparing the economic benefits presented in equations (18) and (20), it is clear that total economic benefits measured based on irrigation water application and presented in equation (19), $B(W: P_w)$, are overestimated. The overestimation bias of equation (19) is represented by $(1 - \gamma)B(W: P_w)$. These results indicate then that the nonlinear irrigation water demand case is consistent with the case of a linear irrigation water demand function.

The inverse irrigation water demand functions presented in equations (16) and (17) are represented in Figure 3. For a given unit cost of irrigation water, *r*, total net economic benefits estimated based on consumptive irrigation water use are represented by the area rBC less the area W*CDW. Total net economic benefits estimated using an irrigation water demand function based on irrigation application are represented by the area rAD. The magnitude of the overestimation bias, then, is represented by the sum of the areas ABCD and the area W*CDW.

3. Application to the Nebraska Mid-state Area

Since most acreage in the Central Platte Natural Resources District (CPNRD) of Nebraska are allocated to continuous corn production to meet local demand for

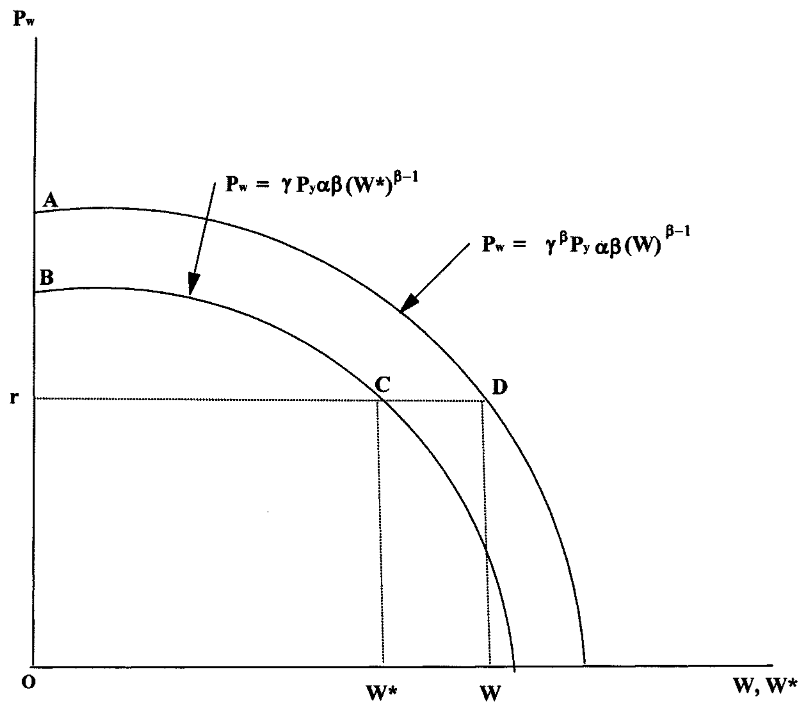

Figure 3. Nonlinear irrigation water demand curves based on applied water (*W*) and consumptive irrigation water (*W**) use.

livestock production, a multiple-inputs/single-output normalized profit function (Huffman and Evanson 1989; Shumway 1983) is employed to derive the supply of corn, the demand for nitrogen fertilizers, and the demand for irrigation groundwater. This function specification imposes homogeneity in prices, is self-dual, and results in linear input demand and output supply functions. Pooled data, for the period 1960–1990 and grouped for Buffalo, Hall and Merrick counties which are located within the Nebraska Mid-State area, are used to estimate the corn supply function and the fertilizer and irrigation water demand functions. Seemingly Unrelated Regression estimates are presented in Table I (Kim and Gollehon 1995).

Independent variables in the irrigation water demand function are expected output prices, current input prices, and fixed input quantities. Expected output prices (dollar per bushel) are included for corn and soybeans. Current input prices are included for nitrogen fertilizers (dollar per nutrient pound) and irrigation water (dollar per acre-inch). Exogenous variables are included for precipitation and cooling degree-days. Time is used to represent temporal shifts in the input requirements function due to irrigation technology change (Shumway 1983). Expected price is simply defined as the higher of the lagged output price or the support price. All price variables are normalized by dividing each price by the sum of farm equipment operation and repair costs per acre.

Table I. Seemingly unrelated regression estimates of the corn supply, nitrogen fertilizer demand, and irrigation water demand: The Nebraska Mid-State region, 1960–90.

Variables	Corn supply	N-demand	Water demand
Normalized prices			
Corn	1,665.56 (1.01)[a]	3,630.97 (4.92)	186,029.12 (0.79)
Soybeans	−340.16 (−0.94)		
N-fertilizer	14.38 (0.94)	−57.09 (−7.33)	−5,355.43 (−2.29)
Irrigation water	−21,701.82 (−1.01)	15,383.32 (1.36)	−19,304,952.00 (−4.82)
Nebraska steer	95.17 (6.13)		
Non-price variables			
Time	496.30 (8.64)	98.35 (3.94)	−21,280.28 (−2.38)
Harvested corn acreage	0.12 (13.09)	0.06 (12.58)	
Irrigated corn acreage			29.94 (14.98)
Percent irrigated corn acres	18,272.46 (3.81)	2,731.16 (1.36)	
D1[b]	−1,580.81 (−1.91)	65.59 (0.15)	−315,291.79 (−2.92)
D2[b]	−1,315.45 (−1.79)	499.63 (1.25)	−94,980.08 (−0.80)
Cooling degree days			
Preplant	–	–	325.65 (0.72)
Growing season	–	–	1,464.08 (−7.56)
Fall season	–	–	−576.32 (−1.55)
Precipitation			
Preplant	–	–	−4,793.06 (−0.38)
Growing season	–	–	−62,529.27 (−6.98)
Fall season	–	–	−93,809.17 (−7.36)
Intercept	−27,608.12 (−5.61)	−3,034.31 (−1.61)	−1,661,040.77 (−2.46)
Adjusted R^2	0.94	0.95	0.93

[a] Number in parentheses represent asymptotic *t*-statistics.
[b] D1 = 1 for Hall county and D2 = 1 for Merrick county.

Data on corn price are from Agricultural Prices during 1960–1990. Data on fertilizer price and nitrogen fertilizer use are from Vroomen and Taylor (1992). County-level weighted cost to pump one acre inch is used for irrigation water price. All other data are from Nebraska Agricultural Statistics during 1960–1990 and the CPNRD. The signs of most parameter estimates correspond to *a priori* expectations. Estimates of own-price coefficients, except for corn, are significant at the 0.01 level. Local consumption by livestock for much of the locally produced corn would account for the insignificant estimate for corn's own-price coefficient. This hypothesis is supported by the significance of the Nebraska steer price coefficient in the corn supply equation (Table I).

Collapsing all of the variables on their geometric means, except for irrigation groundwater quantity and pumping cost by county, the inverse irrigation water demand functions associated with equation (9) are represented as follows.

3.1. Irrigation water demand functions based on application

$$\begin{aligned} \text{Buffalo county: } P_w/r_m &= 0.1746 - 0.000000051(W_j), && (21)\\ \text{Hall county: } P_w/r_m &= 0.1914 - 0.000000051(W_j), && (22)\\ \text{Merrick county: } P_w/r_m &= 0.1676 - 0.000000051(W_j), && (23) \end{aligned}$$

where the variable r_m represents the sum of farm equipment operation and repair costs per acre and the variable W_j represents the average amount of irrigation water use (in acre-inches) for a conventional furrow irrigation technology and a sprinkler irrigation technology. Total irrigated land allocated for corn production in the CPNRD during 1989 comprised 32% of irrigated land using a sprinkler irrigation system and the remaining irrigated land using a conventional furrow irrigation system. Irrigation efficiencies are considered to be 85% and 65% for the sprinkler and conventional furrow irrigation systems, respectively (Williams et al. 1997). Therefore, a weighted average irrigation efficiency is calculated to be γ = 0.714 = [(0.32)(0.85) + (0.68)(0.65)].

Using the weighted average irrigation efficiency of γ = 0.714, the consumptive irrigation water demand functions associated with equation (4) are derived from equations (21) through (23) and represented as follows.

3.2. Consumptive irrigation water demand functions

$$\begin{aligned} \text{Baffalo county: } P_w/r_m &= 0.1746 - (0.000000051)/(0.714)(W^*)\\ &= 0.1756 - 0.000000071(W^*), && (24)\\ \text{Hall county: } P_w/r_m &= 0.1914 - 0.000000071(W^*), && (25)\\ \text{Merrick county: } P_w/r_m &= 0.1676 - 0.000000071(W^*). && (26) \end{aligned}$$

Conventional aggregate estimates of net economic benefits resulting from applied irrigation water use for irrigated corn production, associated with equation (10) for Buffalo (B), Hall (H), and Merrick (M) countries, are estimated using equations (21) through (23) as follows:[3]

$$\begin{aligned} NB_B &= \int_0^{2,637,333} [0.1746 - 0.000000051(W)]\delta W - (2{,}637{,}333 \text{ ac. inch.}\\ &\quad \times \$0.04/\text{ac. inch.})\\ &= \$177,619. && (27)\\ NB_H &= \int_0^{2,960,786} [0.1914 - 0.000000051(W)]\delta W - (2{,}960{,}786 \text{ ac. inch.}\\ &\quad \times \$0.04/\text{ac. inch.})\\ &= \$224,724. && (28) \end{aligned}$$

$$\begin{aligned} NB_M &= \int_0^{2,502,783} [0.1676 - 0.000000051(W)]\delta W - (2{,}502{,}783 \text{ ac. inch.} \\ &\quad \times \$0.04/\text{ac. inch.}) \\ &= \$159,625, \end{aligned} \tag{29}$$

where all economic benefits are expressed in terms of a normalized irrigation water price.

However, correct aggregate net economic benefits based on consumptive irrigation water use for corn production, associated with equations (7) and (13), are represented as follows:[4]

$$\begin{aligned} NB_{B^*} &= \int_0^{1,883,056} [0.1746 - 0.000000071(W^*)]\delta W^* - (2{,}637{,}333 \text{ ac.} \\ &\quad \text{inch.} \times \$0.04/\text{ac. inch.}) \\ &= \$97,409. \end{aligned} \tag{30}$$

$$\begin{aligned} NB_{H^*} &= \int_0^{2,114,001} [0.1914 - 0.000000071(W^*)]\delta W^* - (2{,}960{,}786 \text{ ac.} \\ &\quad \text{inch.} \times \$0.04/\text{ac. inch.}) \\ &= \$127,539. \end{aligned} \tag{31}$$

$$\begin{aligned} NB_{M^*} &= \int_0^{1,786,987} [0.1676 - 0.000000071(W^*)]\delta W^* - (2{,}502{,}783 \text{ ac.} \\ &\quad \text{inch.} \times \$0.04/\text{ac. inch.}) \\ &= \$86,025. \end{aligned} \tag{32}$$

where all monetary terms are again expressed in terms of a noramlized irrigation water price.

Results obtained from equations (27) through (32) are presented in Table II. If the amount of irrigation water applied is used to estimate benefits, then aggregate economic benefits resulting from irrigation water use for corn production would be overestimated by nearly 29% (i.e., $1 - \gamma = 0.286$). However, results indicate that net economic benefits would be overstated by 82% for Buffalo county, 76% for Hall county, and 86% for Merrick county.

These results have very significant implications for water conservation policy. Larger estimates of economic benefits resulting from a model misspecification would encourage farmers to use more water for irrigation. For those locations where the groundwater table level is declining and groundwater is the sole source of irrigation water, a model misspecification problem would lead to increased irrigation water use and reduce incentives for farmers to adopt improved irrigation technologies.

Table II. Economic benefits (EB), costs, and net benefits (NB) associated with irrigation water use for three countries in mid-State Nebraska.

County	Conventional estimates			Corrected estimates		
	EB	Cost	NB	EB	Cost	NB
			($million)[a]			
Buffalo	283.1	105.5	177.6	202.9	105.5	97.4
Hall	343.1	118.4	224.7	246.0	118.4	127.5
Merrick	259.7	100.1	159.6	186.1	100.1	86.0

[a] Valued in terms of normalized irrigation water prices.

4. Conclusions

Since economic surplus generated from activity in an input market measures scarcity rents to producers plus consumer's surplus in the product market under general-equilibrium competitive conditions (Just and Hueth 1979), then an indirect profit-maximization approach can be used to measure the economic benefits resulting from the use of irrigation water in agriculture. This indirect approach avoids the complexities associated with the estimation of multiproduct-multifactor production function(s) of irrigation water. Recently, however, there has been a controversy over whether the area behind an irrigation water or nitrogen fertilizer demand curve correctly represents economic benefits resulting from the use of irrigation water or nitrogen fertilizer (Gisser and Johnson 1983; Kim et al. 1997a, b). This research identifies the misspecification inherent with the conventional specification of these models for irrigation water use, and then measures the effects of the misspecification bias on the measure of economic benefits resulting from irrigation water use.

A numerical example demonstrates that when the quantity of irrigation water applied is used with an indirect profit-maximization approach, rather than the consumptive-use quantity, the total economic benefits resulting from irrigation water use for corn production within a three-county area in the Nebraska Mid-State area would be overestimated by 28.9%. This relative impact represents the rate of irrigation water losses through leaching, runoff and evaporation. Furthermore, when the derived irrigation water demand function is based on applied water, results for this study area indicate that net economic benefits would be overestimated by 82% for Buffalo county, 76% for Hall county, and 86% for Merrick county.

From a resource policy perspective, these results are significant. Overestimating economic benefits associated with a given irrigation investment can certainly present an illusion of maximum economic efficiency. However, this illusion can result in under-investment in water-conserving irrigation technology. The practical policy implication here is that overestimation of economic benefits may also have the effect of discouraging the need for public-sector investment incentives when these incentives would promote both water quality and water conserving goals.

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Notes

1. The paper does not question the theoretical foundations of the indirect profit maximization approach here. However, the paper will demonstrate a misspecification bias attributable to the implementation of this theoretical construct unique to the estimation of economic benefits associated with irrigation water or nitrogen fertilizer use in agriculture.
2. The relationship between irrigation efficiency and applied irrigation water is expressed in simpler terms here in order to emphasize the theoretical issues associated with misspecification bias using a traditional production function approach. Equation (1) does however imply a more complex and general relationship, that is, $\gamma = f(W^*/W)$. While a general case may account for such factors as weather conditions that result in a stochastic element to consumptive water use, such a case does not alter the theoretical or empirical results presented in this paper. The more general case, however, involves irrigation issues beyond the scope of this paper.
3. The upper limit of the integral represents the average amount of irrigation water use in acre-inches.
4. The upper limit of the integral represents the average amount of consumptive irrigation water use estimated with equation (1).

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